A CANDIDATE ICE-MARGINAL PALEOLAKE ASSOCIATED WITH AMAZONIAN-AGED BURIED GLACIERS AND CANDIDATE ESKERS ON MARS.

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Summary: We present the discovery of a possible glacial paleolake associated with geologically-young (~150 Ma, i.e., late Amazonian-aged) buried glaciers (termed 'viscous flow features', VFFs) in the Tempe Terra region of Mars' northern mid latitudes (Fig 1a). The candidate paleolake, which we interpret as proglacial, is evidenced by two sinuous ridges which extend from extant buried glaciers, and terminate in fans (Fig 1b) adhering to an equipotential contour within a deep, topographically-confined basin that has no obvious drainage outlet. We interpret the two sinuous ridges as eskers: ridges of sediment deposited by meltwater draining through tunnels beneath glacial ice.

The identification of these two candidate eskers, and a previously unreported candidate esker to the north (Fig 1c), means that eskers have now been identified extending from seven extant buried glaciers in Tempe Terra [1, 2, 3, this study], including all six major glaciers on the eastern flank of the mountain chain along the western margin of the province (Fig 1c) [1, 2, this study]. This provides increasing confidence that regionally-extensive, warm-based or polythermal glaciation occurred in Tempe Terra during the Amazonian, and suggests that we have an incomplete understanding of Mars' geologically recent environmental conditions.

Here we pursue an important open question, raised by [4], which could help constrain the environmental conditions that permitted basal melting of glaciers on Amazonian Mars: what was the fate of subglacial meltwater upon exiting pressurized ice-confined conduits and entering proglacial environments?

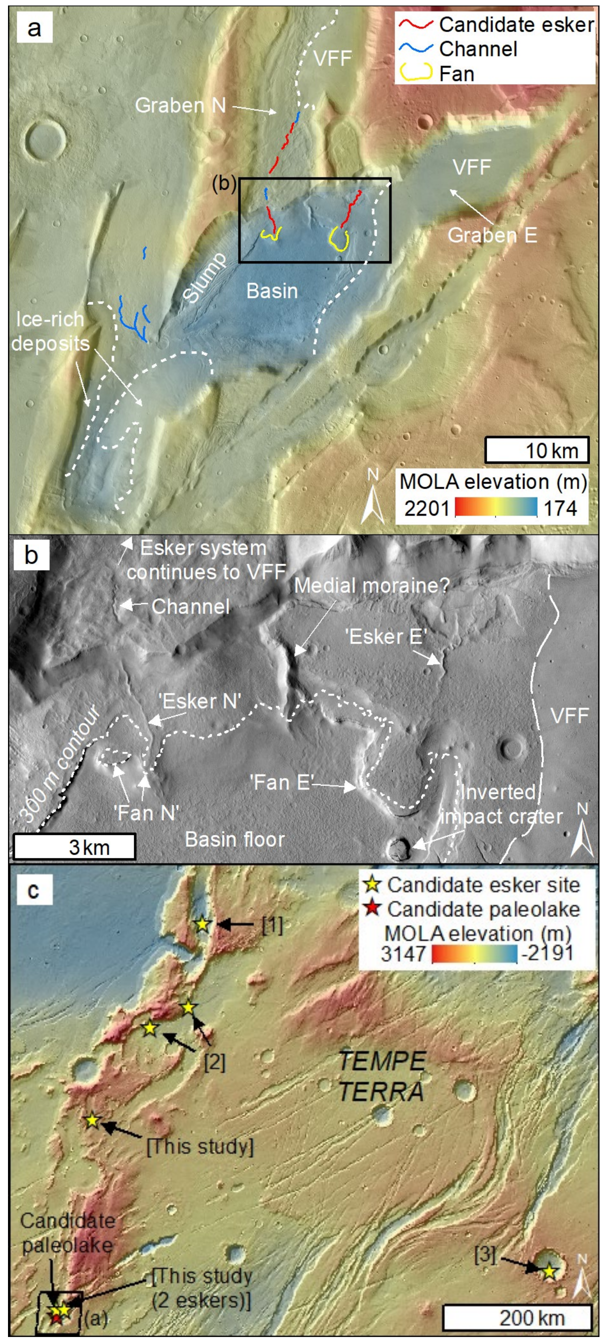

Fig 1 (right): ***(a)*** *Candidate glacial paleolake basin associated with two candidate eskers with terminal fans extending from buried glaciers (dotted lines show VFF margins). Context Camera (CTX) images overlain by Mars Orbiter Laser Altimeter (MOLA) elevation map. Extent in c.* ***(b)*** *CTX images of the candidate esker-fan systems in the hypothesized paleolake basin. Extent in a. Dotted line is 300 m contour from CTX DEM. Dashed line is VFF terminus* ***(c)*** *MOLA elevation map showing 7 candidate glacier-linked esker sites in Tempe Terra, and extent of panel a (black box).*

Study Location: The candidate glacial paleolake basin (86.5°W, 37.4°N), hosting two candidate glacier-linked eskers (Fig 1a–b), is located in Western Tempe Terra (Fig 1c). It is ~400 km SSW of two candidate glacier-linked eskers identified by [2], ~550 km SSW of a glacier-linked esker identified by [1], and ~650 km WSW of possible (but lower-certainty) glacier-linked eskers in Chukhung Crater identified by [3]. Another previously unreported candidate glacier-linked esker is located ~260 km N of the candidate paleolake (Fig 1c).

Methods: We present geomorphic evidence compiled from a basemap of 6 m/pixel CTX images supplemented by more localized 25 cm/pixel High Resolution Imaging Science Experiment (HiRISE) images, and 1 m/pixel HiRISE, ~20 m/pixel CTX, and 463 m/pixel Mars Orbiter Laser Altimeter (MOLA) digital elevation models (DEMs). We analyzed contour maps from the CTX DEM to assess the relative elevations of layers within the esker-terminal deposits and erosional remnants of basin-filling materials. We estimated the surface ages of the two buried glaciers associated with the candidate eskers by analyzing the size-frequency distributions of impact craters on their surfaces. We take this as an approximate absolute minimum age of the candidate eskers and paleolake.

Observations and Interpretations: The candidate glacial paleolake basin is a 15 km-wide rhombus-shaped depression bounded by higher topography up to ~1.2 km above the basin floor. The lowest potential spillways are ~600 m above the basin floor (Fig 1a). Two grabens, hosting VFFs, extend towards the basin from the east (graben E) and north (graben N). The VFFs have a combined estimated surface age of ~150 Ma, consistent with those at candidate esker sites elsewhere on Mars (110 Ma [5], 150 Ma [1], 220 Ma [2], 330 Ma [3]). This probably underestimates the true age of the glacial landsystem (e.g., due to crater erasure by ice retreat) but is confidently mid-to-late Amazonian, showing that the landsystem is geologically young.

The VFF in graben E terminates near the edge of the basin (Fig 1a). An esker-like sinuous ridge (ridge E) extends ~2 km from near to the VFF margin, towards a ~2×2 km fan-shaped feature (fan E), which protrudes into the basin and appears to comprise multiple stratigraphic layers evidenced by topographic steps around its margins (Fig 1b). The elevation contour that adheres to the upper level of fan E (~300 m) traces remarkably closely around a scarp surrounding the terminal zone of a second esker-like sinuous ridge which extends southward from graben N (esker N; Fig 1b). This suggests that the eskers could have terminated at an equipotential surface such as a lake. The terminal segment of esker N is connected to a VFF in graben N by a ~12.5 km-long system of esker-like ridge and channel segments (Fig 1a). The terminal ridge segment begins at the base of a ~10° slope-face of a tectonic fault scarp which we interpret as pre-dating glaciation. NE-SW oriented streamlined landforms on the central portion of the basin floor, and erosional scarps around its margins, suggest that aeolian erosion has partially removed basin infill. Contour tracing around the scarps suggests that floor-filling materials were very flat prior to partial removal, supporting a potential lacustrine origin. This is exemplified by the correlation of the upper surface of a circular mesa, which we interpret as an inverted impact crater (Fig 1b) with a scarp in fan E. Formation of these deposits in a subglacial lake remains a possibility, but we currently favor proglacial origins.

Discussion and Conclusions: We present a candidate paleolake basin associated with late-Amazonian-aged (~150 Ma) buried glaciers in Mars' Tempe Terra region, which suggests subglacial meltwater could have ponded proglacially during the Amazonian. Under Mars' low contemporary atmospheric pressure (~6 mbar), liquid water is unstable at the surface. However, even if atmospheric pressure was similarly low during the mid-to-late Amazonian high-volume, sediment-laden flows exiting pressurized subsurface environments (such as esker-forming flows) could have persisted for some time before boiling away, percolating into the ground, and/or refreezing [e.g., 6–7]. Formation of an ice cover could have protected underlying water from rapid loss to the atmosphere.

Previous studies of glacier-linked eskers on Mars have invoked localized geothermal heating as a possible primary driver of basal melting and esker formation [1–5]. The regionally-extensive esker distribution and evidence for meltwater ponding we present suggests that climate change, and possibly higher atmospheric pressure, should be given closer consideration as potential drivers of warm-based/polythermal glaciation on Amazonian Mars.

Acknowledgments: We acknowledge funding from a Leverhulme Trust Early Career Fellowship (FEGB), the ERC European Union's Horizon 2020 research and innovation programme (grant 787263; CDC), the French Space Agency CNES (SJC), NERC (NE/R014574/1; JCE), SNSA (grant-C 195/15; AJ), UK Space Agency (ST/W002949/1; SRL), and STFC (ST/V50693X/1; SZW).

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